Evaluation of a musculoskeletal finite element model of the foot

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This work aims at developing a patient-specific Finite Element (FE) model of the foot in the context of pressure ulcer prevention. Starting from our previous model {1} we propose here to improve the realism of the anatomy by introducing all the detailed bony structures, ligaments and muscles segmented from the CT and MRI exams of the same patient. The model has been developed using the 3D biomechanical simulation platform Artisynth (artisynth.org). It includes 30 bones modeled as articulated rigid-bodies connected with cables that simulate the 210 segmented ligaments in their actual positions and therefore define the articulations. The aponeurosis is modeled with fives parallel multipoint ligaments. A set of 15 extrinsic and intrinsic muscles based on linear axial muscle activation law is anatomically positioned in order to allow a natural movement of the foot.

A FE mesh of the soft tissue was created by applying an automatic FE mesh generator {2} to the surfaces resulting from MRI segmentation. The FE mesh has 95883 elements and 56806 nodes .Three soft tissue layers with Neo Hookean materials (Young moduli, Poisson Ratio) were created to represent a 1mm skin layer (200, 0.485), the fat (30, 0.49) and muscle (60, 0.495) tissues.

The foot model was evaluated by comparing its simulations with the pressure mat collected with the patient standing onto a Zebris FDM platform (www.zebris.de). For this, the patient weight was applied onto the foot model put in contact with anhorizontal plate (figure). Another evaluation of the model aimed at comparing the kinematics of the model resulting from simulated muscle activations with an actual 3D motion analysis of the patient foot {3} coupled with an EMG monitoring of the tibialis posterior, tibialis anterior, soleus, medial gastrocnemius, lateral gastrocnemius and peroneus muscles.

Globally, this new version of the foot model provides realistic simulations in both static and dynamic frameworks. In addition to its use for pressure ulcer prevention, it could become relevant for the simulation of neuro-orthopedic surgical interventions, orthotic devices analysis or educational purposes.

References

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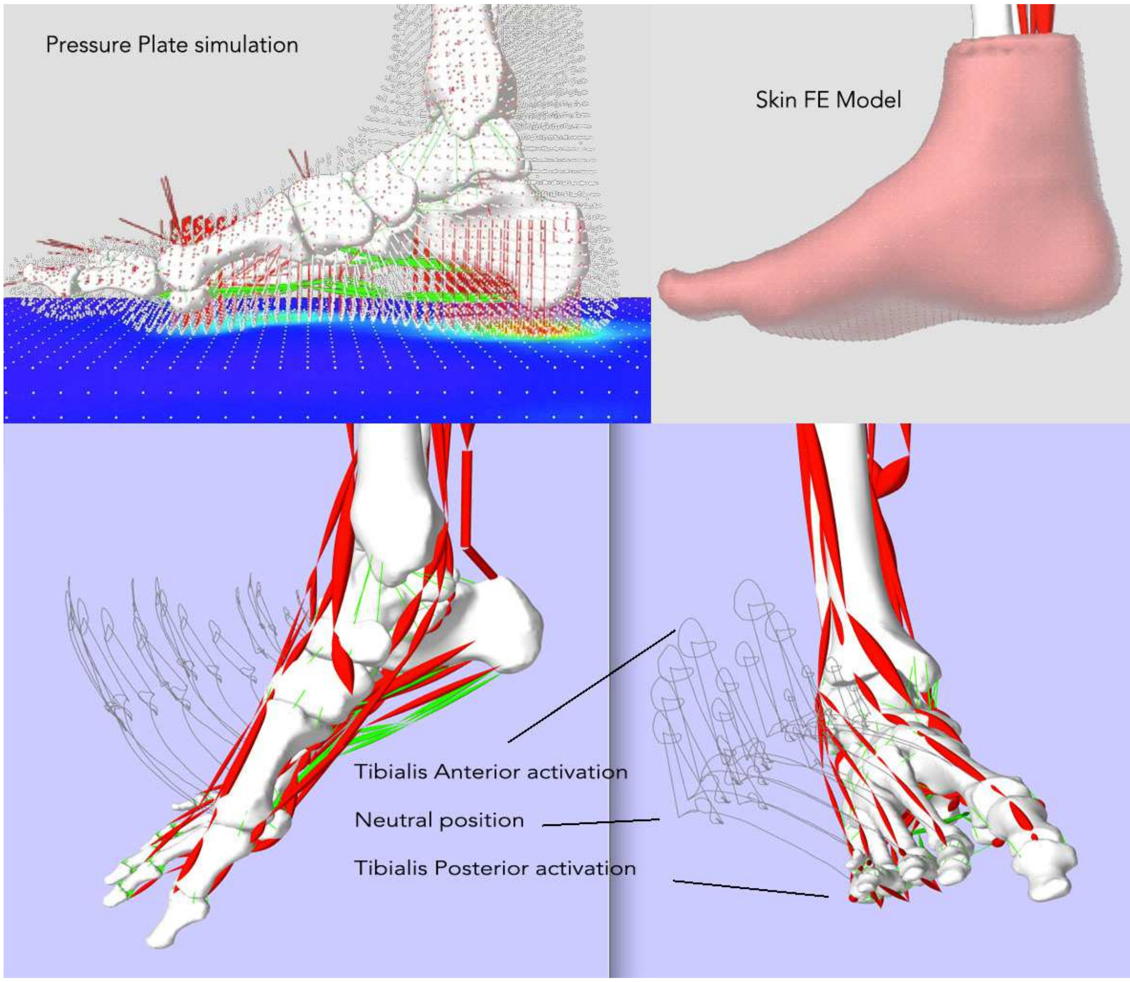
Keywords: foot modeling, finite element analysis, musculoskeletal modeling, Dynamic simulation, EMG muscle activation.


Pressure Plate simulation
Skin FE Model
Tibialis Anterior activation
Neutral position
Tibialis Posterior activation

Figure